Machine Studies in the LHC injectors

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Scenarios for the LHC upgrade and FAIR

November 24-25, 2008)

Abstract

Increasing the LHC pp-collider luminosity by replacing the bunches with Gaussian line-charge distributions with flat distributions, but with same beam-beam tune shift, has been discussed in literature. The luminosity increased can be up to 40% by adopting this technique. Here, we present the preliminary results from recent beam dynamics simulations and from beam studies in LHC upstream machines to create flat bunches using double harmonic rf systems. We used the 200MHz and 800MHz rf systems in the SPS and, 10MHz and 20MHz rf systems in the PS during our beam studies. The studies were carried out to address flat bunch creation technique and its stability issues. We also have presented simulations and discussions on possible way of creation and acceleration of flat bunches in the LHC for luminosity upgrade.

Motivation

- F. Ruggiero et. al.[#] have shown that one can increase the LHC luminosity by 41% ($\approx\sqrt{2}$)!! for the same number of particles and the same total beam-beam tune shift, **by simply flattening** the bunches.

  ← Increasing the Piwinski angle $\phi = \theta_c \sigma_z / (2\sigma^*_x)$ (hence LPA-scheme)

  # http://cdsweb.cern.ch/record/603729/files/lhc-project-report-627.pdf

- Flat bunches of antiproton have been successfully created and are used in daily operation in the Fermilab Recycler.

Hence the interest in flat bunches in LHC !

This led to

- ❑ Beam Studies in LHC Upstream Machines : SPS and PS
- ❑ Study the Prospects at LHC : Possibly benefit even in early operations

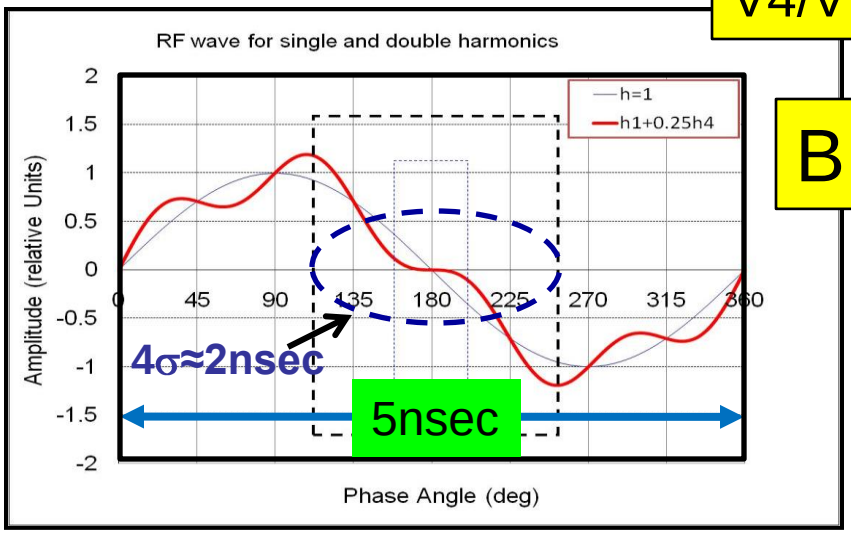
SPS: Beam Studies with double harmonic rf

(Elena Shaposhnikova, T. Bohl, T. Linnecar, J. Tuckmantel and C. Bhat)

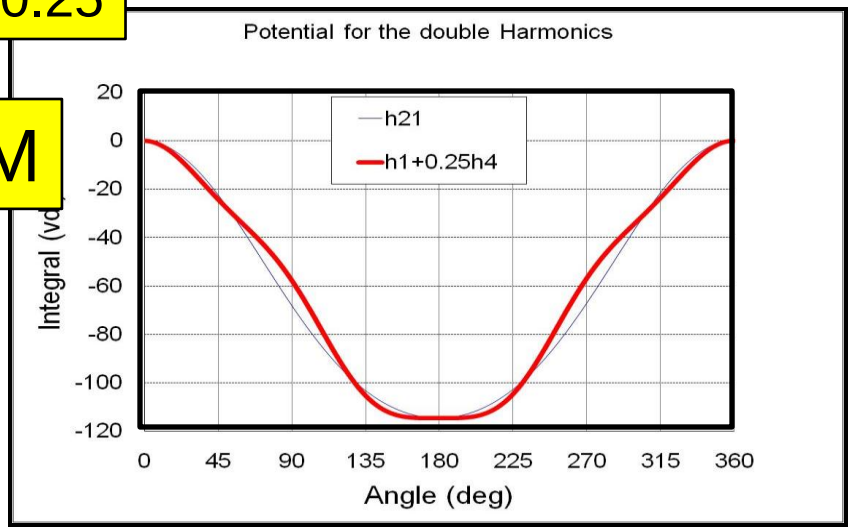
- We have carried out beam studies in the SPS to revisit the beam instability issues in 200MHz+800MHz, (i.e., h=1+h=4) double harmonic rf system(Nov. 5, 2008).
  - ❑ **← development of shoulder in WCM signals of the bunches were seen during similar studies in a coasting beam at 120 GeV/c (E. Shaposhnikova et. al., 2006)**
- Studies were conducted under various conditions at 270GeV Flat top on a coasting beam
  - ❑ **Four LHC type** (intensity and Long. emitt.) bunches, separated by 525nsec
  - ❑ Study Parameters were:
    - ➢ V4/V1, **(V4(100-500kV), V1(1-3MV)**
    - ➢ ON and OFF→ Long. damper and Phase-loop (and phase loop for different bunches)
    - ➢ Bunch lengthening and shortening mode (BLM and BSM)

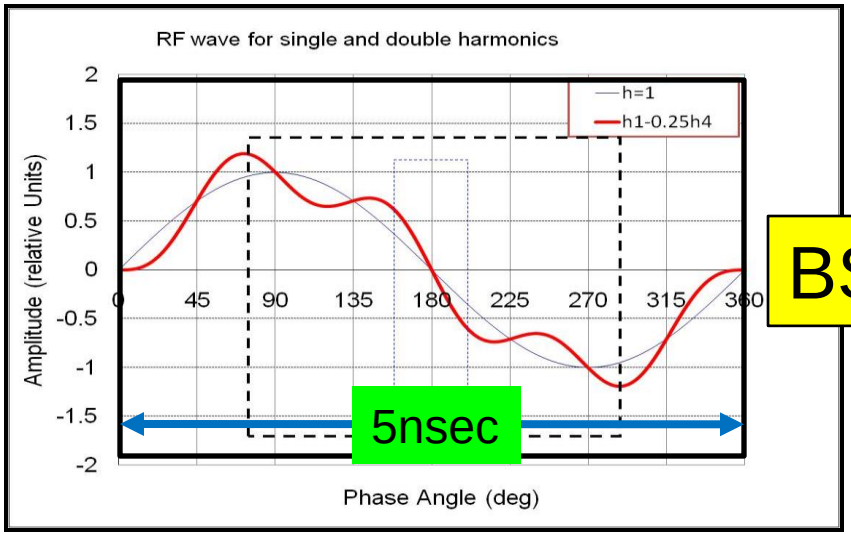
Double RF used in SPS Studies
(wave forms & Integral(Vdt)

V4/V1=0.25

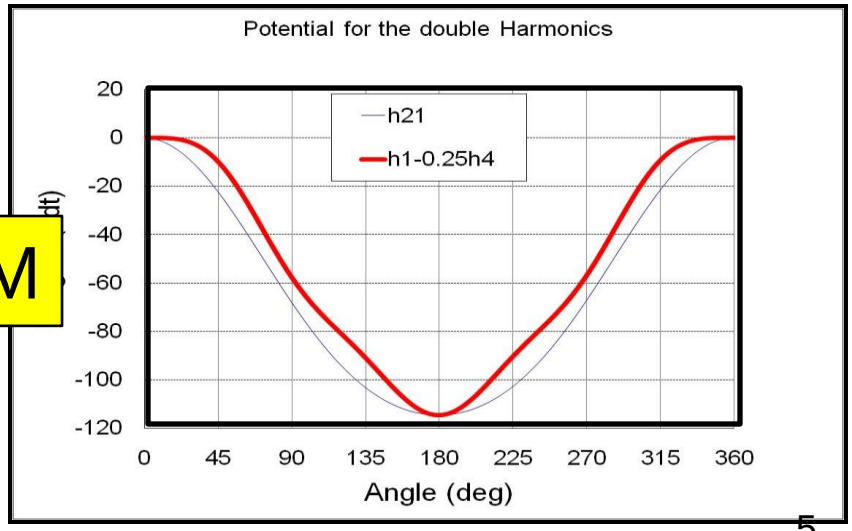


BLM



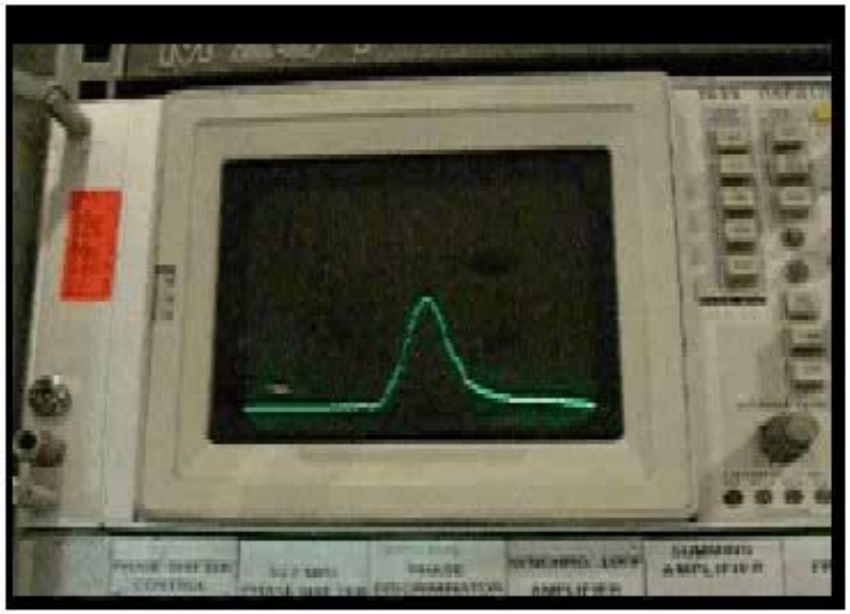


BSM



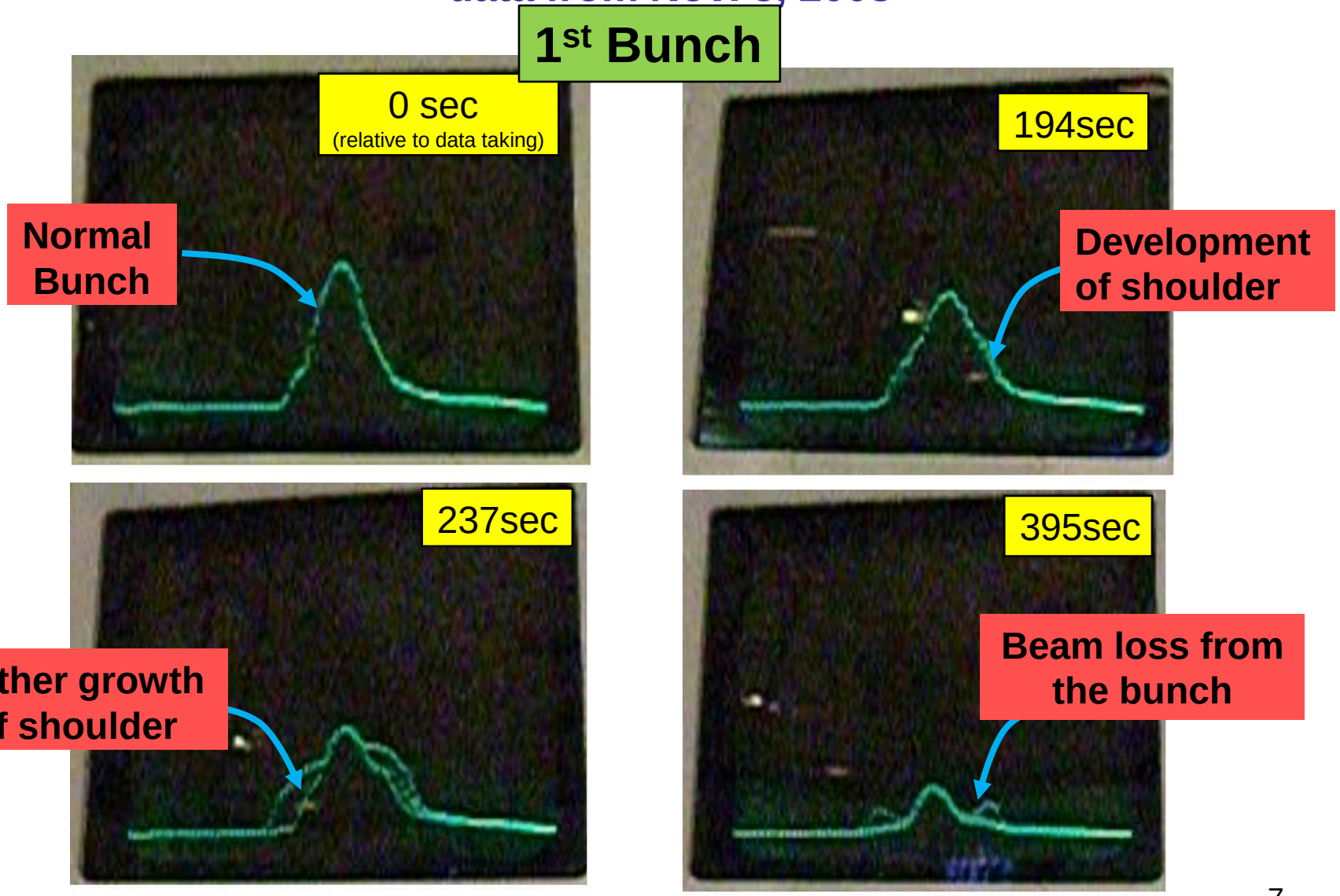
SPS Beam Studies(cont.)
Bunch Lengthening Mode (BLM)
(a first look, Preliminary) data from Nov. 5, 2008

Video data for 3-4 mins on the 1st bunch after setting the rf parameters for BLM (this is an abridged form).

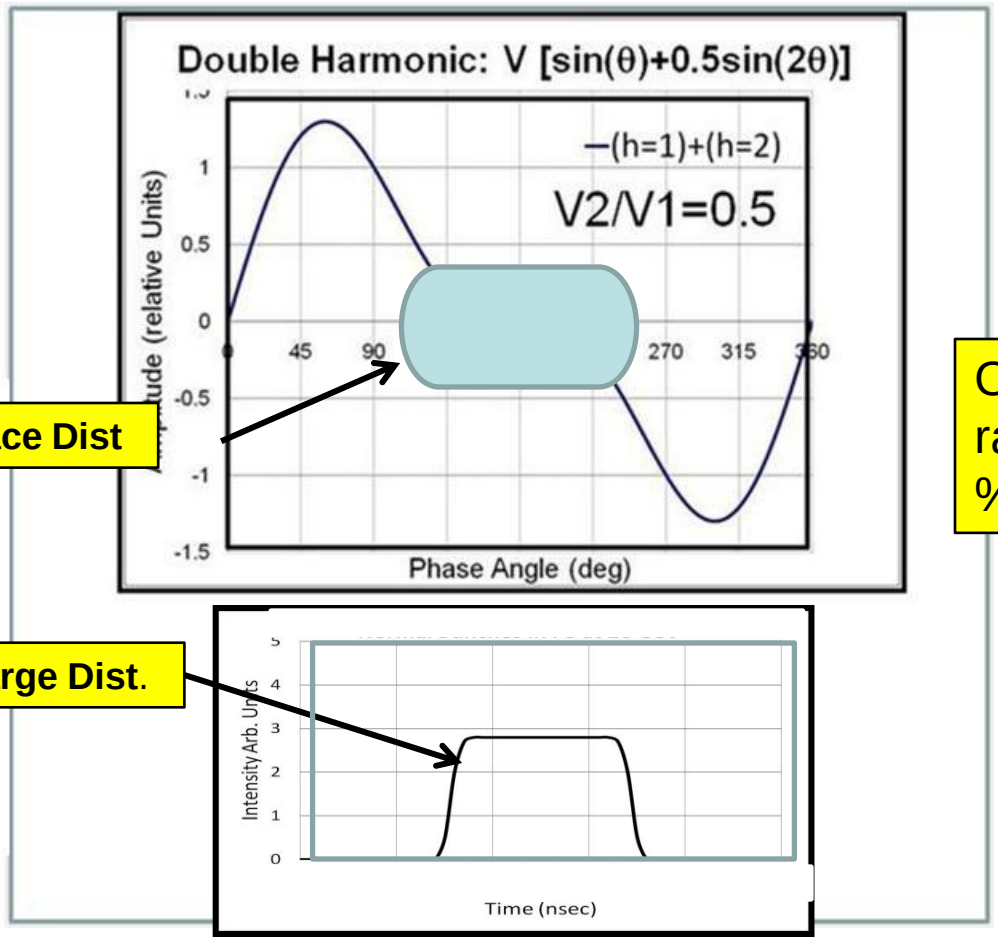


SPS Beam Studies(cont.): BLM

(a first look, Preliminary)
data from Nov. 5, 2008



Double harmonic rf system for flattening the bunches



Phase-space Dist

Line charge Dist.

One can have the ratio V2/V1 a few % higher (<4%)

Flat-Bunches: The bunches with flat or nearly flat line-charge distribution are flat bunches .

Flat bunch creation

- There are twoways to create flat bunches
  - Using resonant rf system
    - Double, triple or multiple harmonic rf system
    - Longitudinal hollow bunches, Carli's technique
  - Barrier rf to generate Flat bunches
    - Fermilab Recycler Flat bunches
    - Flat bunches at KEK

Number of refs. are available in literature on **double harmonic rf system and flat-bunches.**

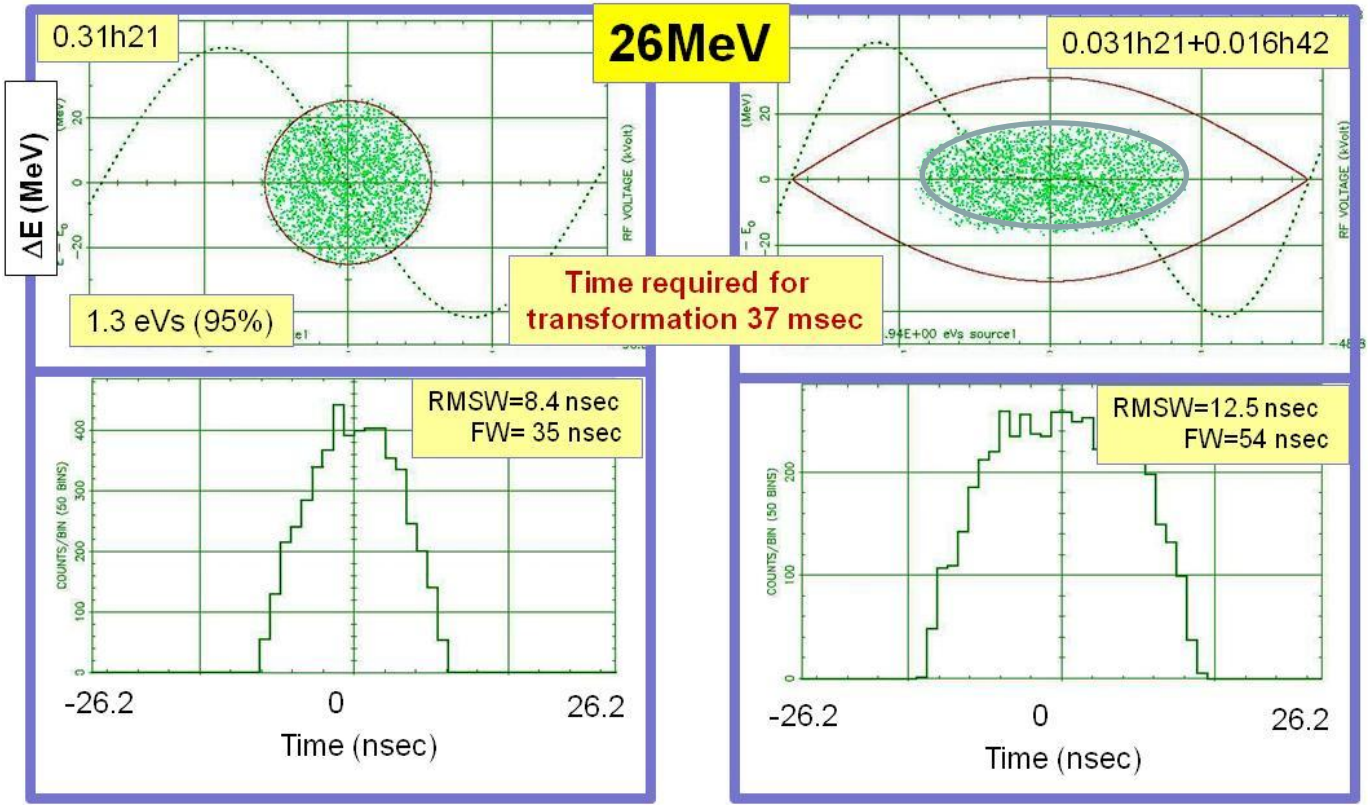
PS: Beam Studies with double harmonic rf

(Chandra Bhat, H.Damerau, S. Hancock, E. Mahner, F. Casper and F. Zimmermann)

- We conducted a beam study in the PS using double harmonic rf system (November 11, 2008)
  - These studies were motivated by beam dynamics simulations (C. Bhat)
  - To investigate the creation and stability of flat bunches
  - Used existing rf system in PS: 10 MHz and 20 MHz rf systems
  - On the LHC25 (normal LHC beam acceleration cycle) with nominal beam parameters (≈8.4E12/72 LHC bunches, ≈25eVs/72 bunches etc.)
- After triple split at 1.4 GeV flat bottom, 18-bunches (~1.4 eVs/each) are accelerated to 26 GeV. Then,
  - rf phase of 20 MHz is set to 180^0 relative to 10 MHz and V2/V1 is changed adiabatically from 0 to 0.51(≈0.016MV/0.031MV) in 35 ms.
  - Monitored the behavior of the bunches till the end of the cycle (~100ms).
  - Monitored e-cloud effect ← **No signal seen**

The phase and voltage ratio **V2/V1≈0.51** was a critical parameter in this study

Evolution of RMSW of Bunches in PS while Flattening

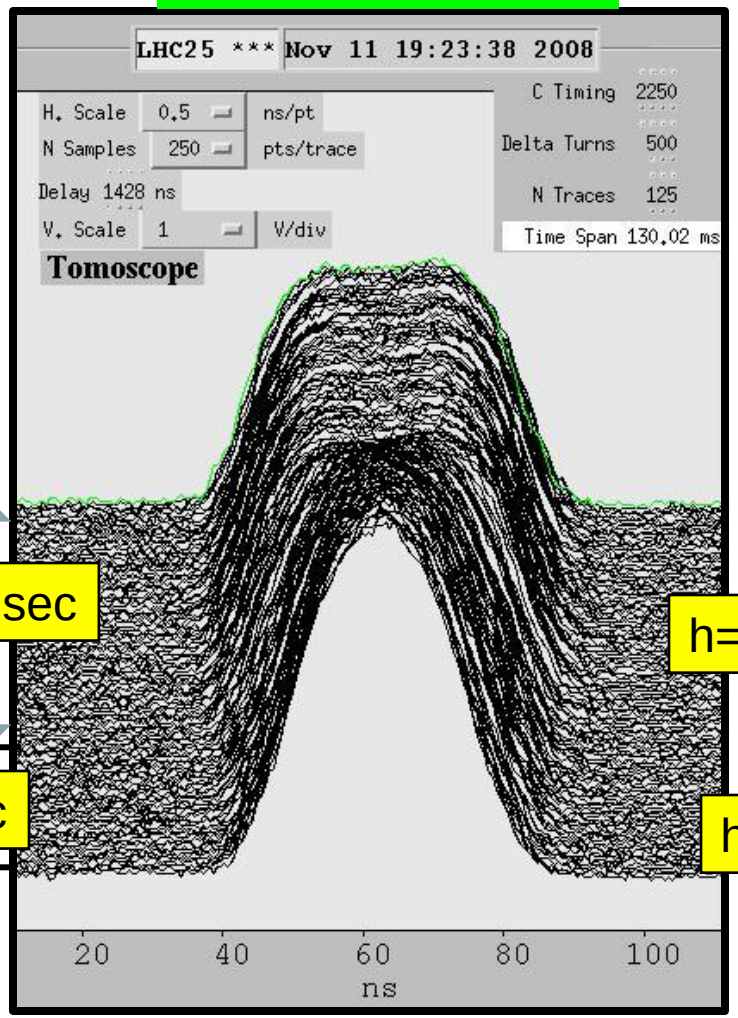


Expected:-- About 50% increase in RMSW from beginning of rf manipulation to the flattened bunch

PS data from 081111-1924 and Simulation

(Preliminary)

Experimental Data



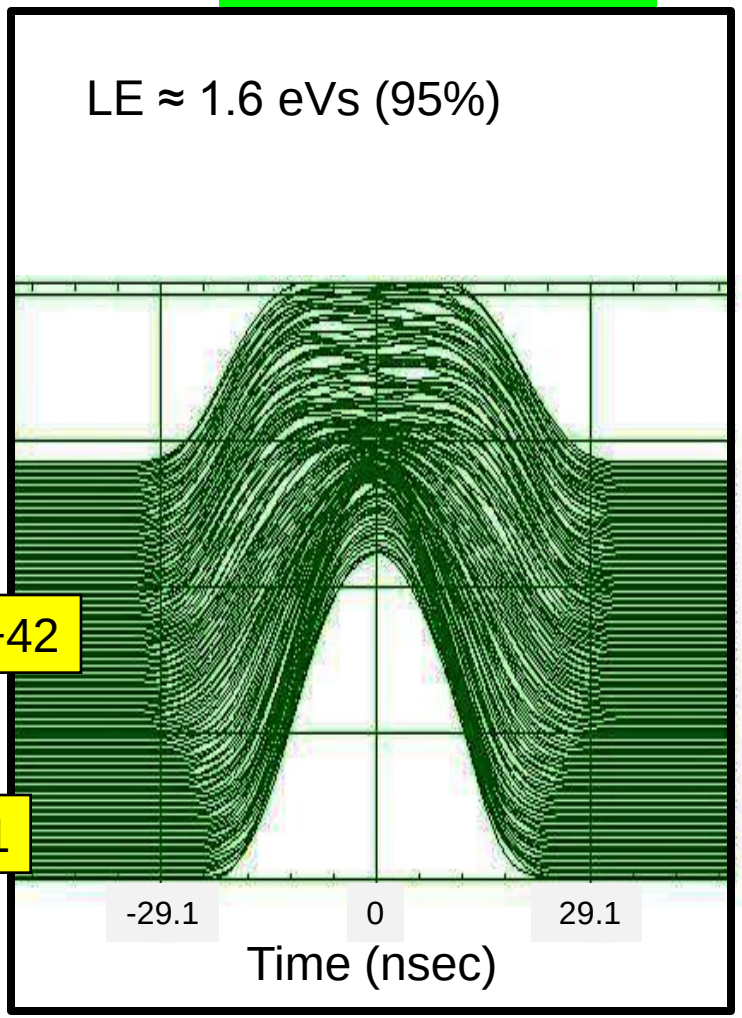
95 msec

35 msec

h=21+42

h=21

ESME Simulation



Δp/p reduced by ≈40%

Beam Stability: A Comparison between Normal and Flat Bunches in PS

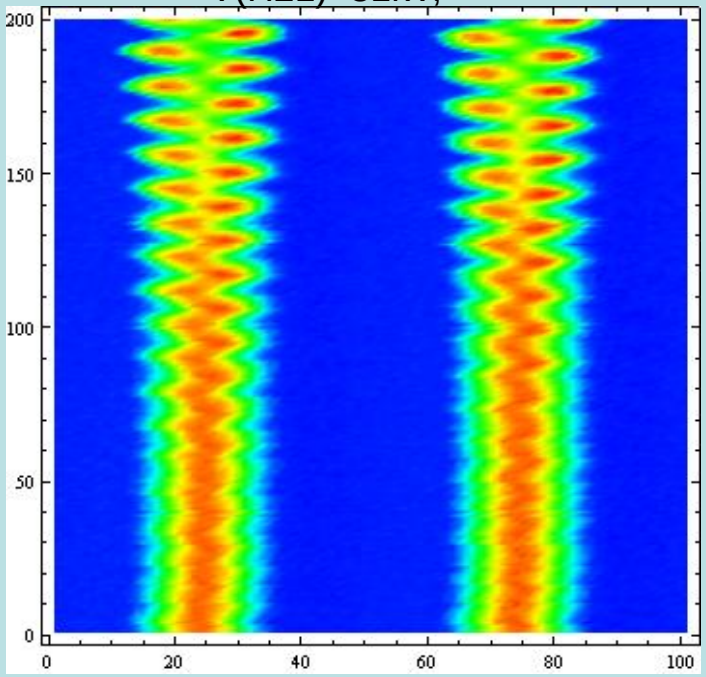
(PS data from 081111)

Last two bunches

Hereward damper off

Standard Bunches

V(H21)=31kV,

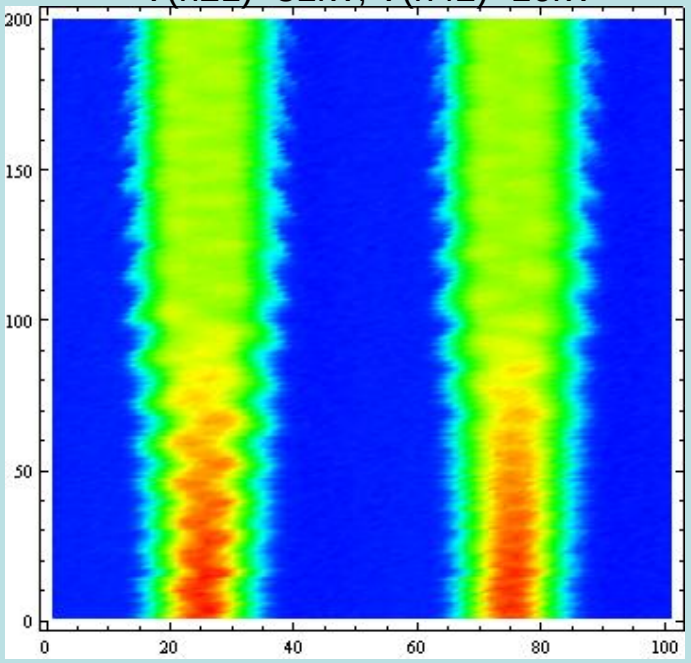


Became more unstable

☹

Flat Bunches

V(h21)=31kV, V(h42)=16kV



Became more stable

☺

Prospects for LHC

- There are two scenarios for flat bunches in the LHC using the 200 MHz (R. Losito et. al, EPAC2004, p956) and **400MHz RF** systems in the Ring.

Main RF system

  - ❑ Create flat bunches at peak energy

    ← **This can be implemented relatively soon**

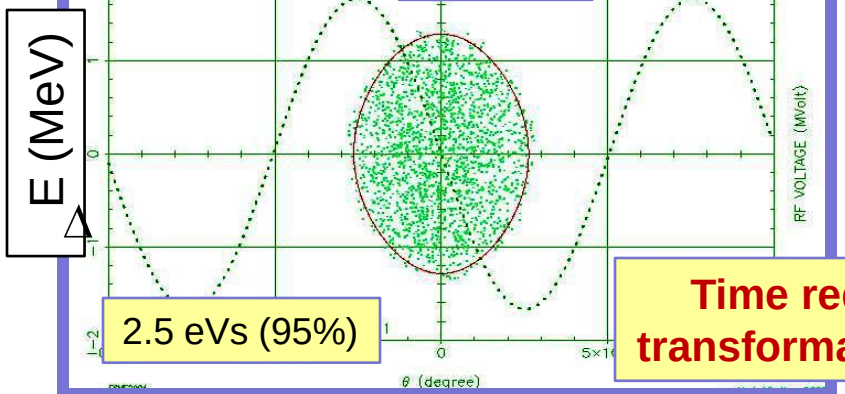
  - ❑ Create flat bunches at injection energy and accelerate to peak energy

    ←**This needs development of additional controls and a bit involved.**

    ← **But the advantage is that dp/p < 3 times smaller than that for normal acceleration case. We may be able to reduce beam losses significantly.**

Evolution of RMSW of Bunches in LHC

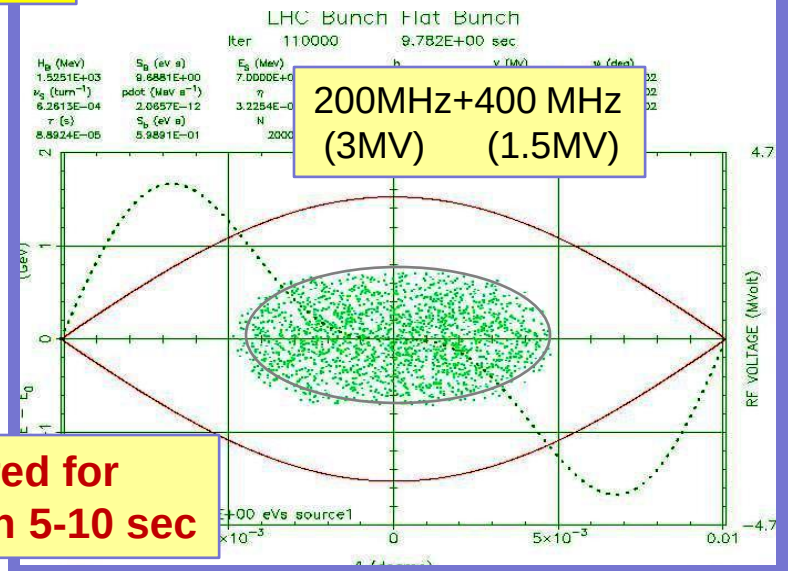
7 TeV



400 MHz (8 MV)

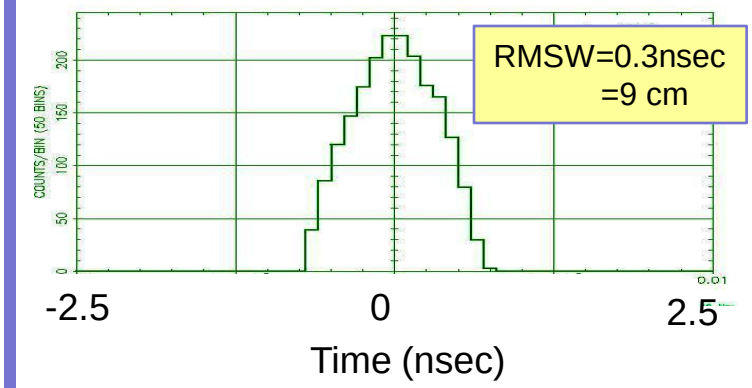
E (MeV)

2.5 eVs (95%)

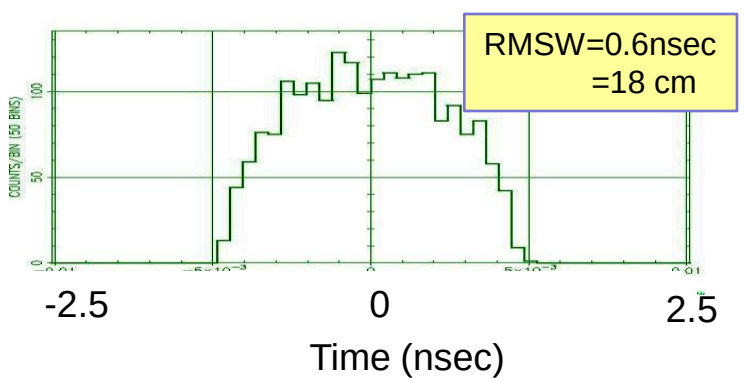


200MHz+400 MHz (3MV) (1.5MV)

Time required for transformation 5-10 sec

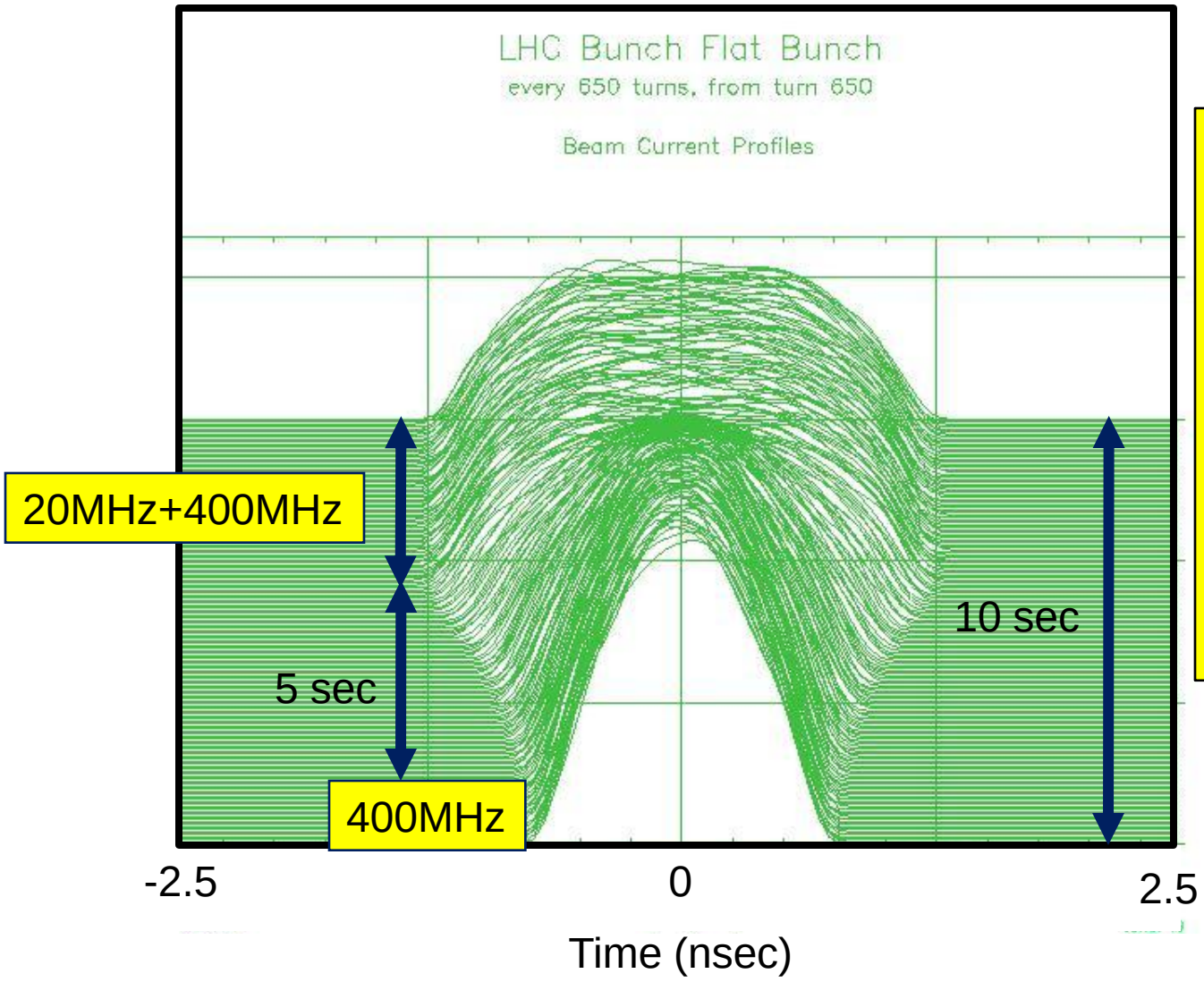


RMSW=0.3nsec =9 cm



RMSW=0.6nsec =18 cm

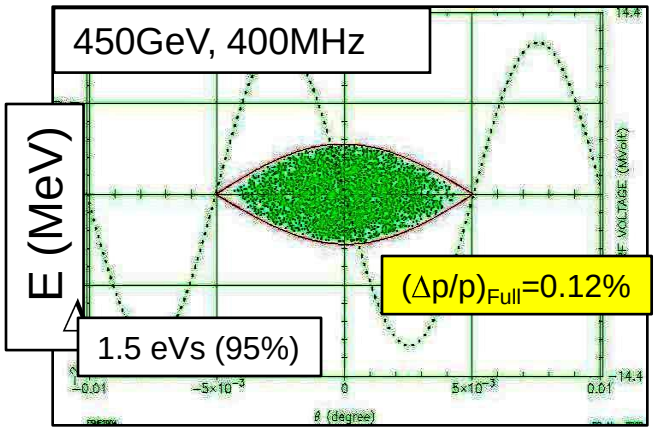
Preparation of Flat Bunches at 7 TeV with 400MHz and 200 MHz rf systems

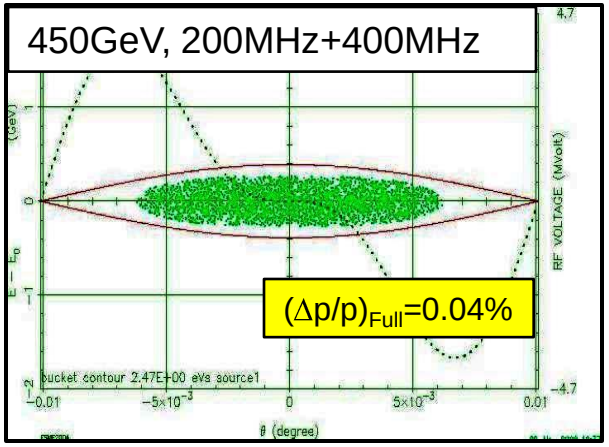


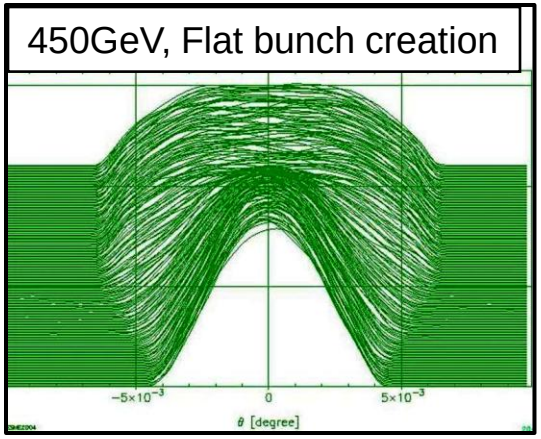
With 200 MHz and 400MHz rf system the bunches in LHC can be flattened. This implies

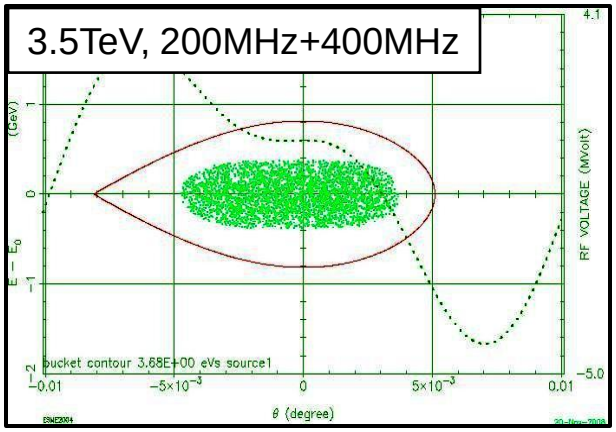
1. LHC luminosity increase of at least 30% for the same beam parameters
2. At least a factor of two less momentum spread for the beam. Hence, less beam loss around the ring.

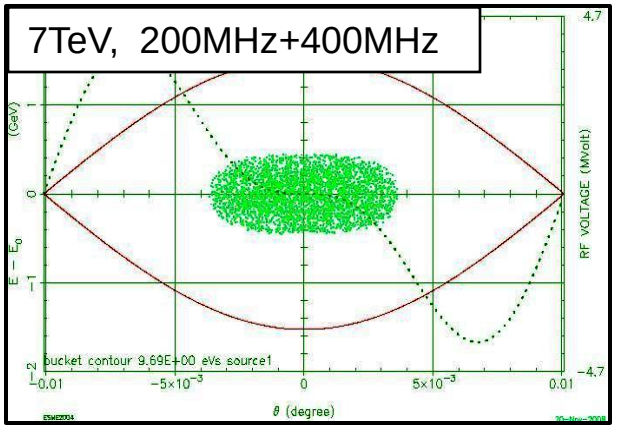
Flat Bunches at Injection & Acceleration using 400MHz and 200 MHz rf systems

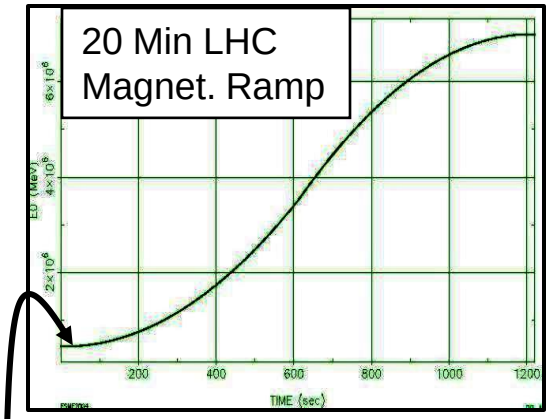












Create Flat Bunches at Inj. energy

Summary and Conclusions

- LHC luminosity can be increased by up to 40% (!!!) for the same number of particles/bunch and emittance, and other machine parameters by using flat bunches.
- **Have carried out simulations and beam experiments to create flat bunches in the injectors (PS and SPS) to address beam instability issue**
  - **some preliminary analysis of the data from MD runs done and the results are promising**
  - **More studies to be undertaken next spring**
- I have presented here a discussion and simulation results on creation and acceleration of flat bunches in the LHC.

Flat bunch scenario for the LHC is a very promising path for the Luminosity upgrade

Acknowledgements

- F. Zimmerman, O. Bruning, E. Metral, R. Garoby and G. Arduini
- SPS Experiments/Discussions
  - E. Shaposhnikova,T.Bohl, T. Linnecar, J. Tuckmantel
- PS Experiment/Discussions
  - H. Damerau, S. Hancock, E. Mahner, F. Casper

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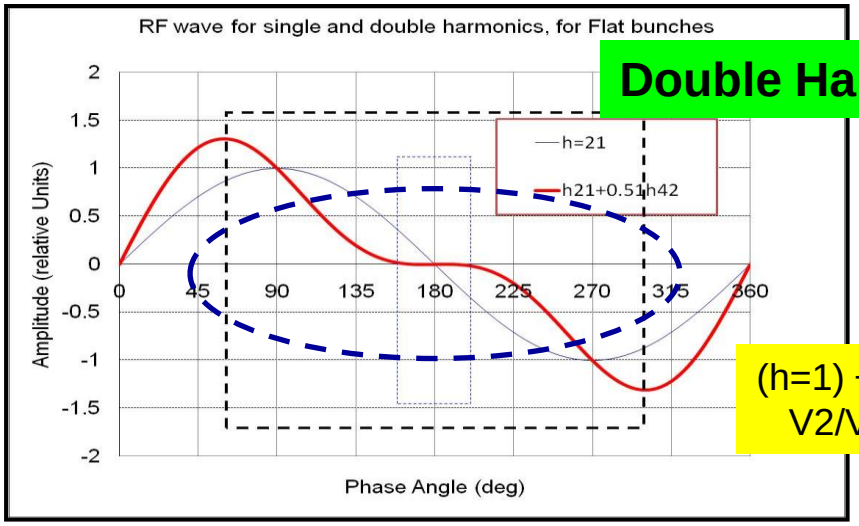
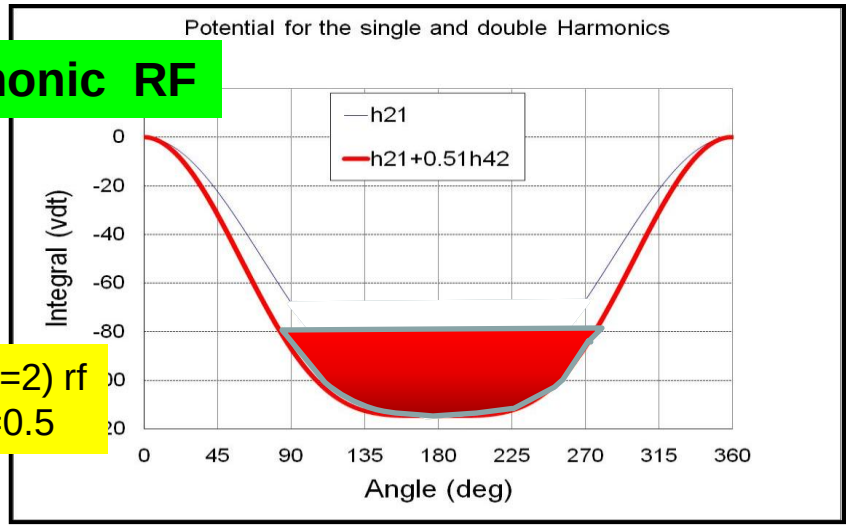
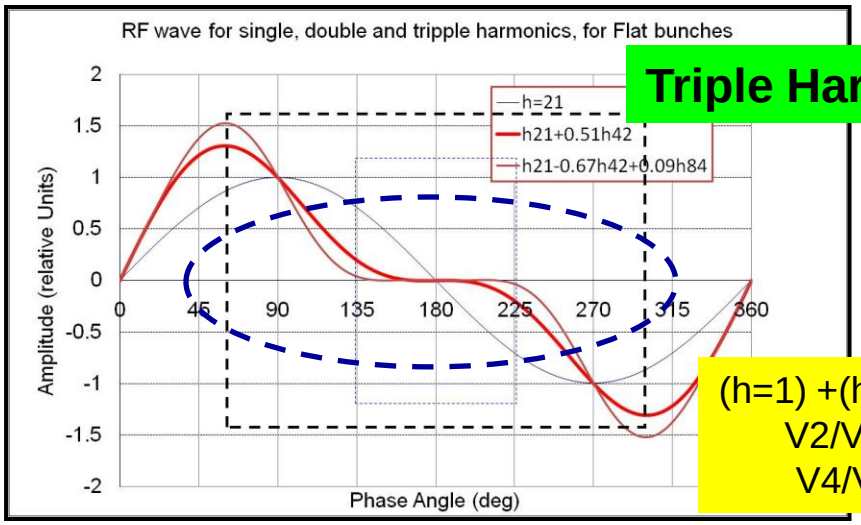
Triple Harmonic RF for Flatter Bunches
(wave forms & Integral(Vdt)



Double Harmonic RF

(h=1) +(h=2) rf
V2/V1=0.5





Triple Harmonic RF

(h=1) +(h=2)+(h=4) rf
V2/V1=-0.67,
V4/V1=0.09